

# APPLICATION UNDER UNITED STATES PATENT LAWS

Atty. Dkt. No. 008312-0307357

Invention: APPARATUS AND METHOD FOR POSITIONING HEAD AT TARGET POSITION ON DISK

Inventor (s): Tatsuharu KUSUMOTO  
Koji YAEHASHI

Address communications to the  
correspondence address  
associated with our Customer No

**00909**

Pillsbury Winthrop LLP

## This is a:

- ☐ Provisional Application
- ☒ Regular Utility Application
- ☐ Continuing Application
  - ☐ The contents of the parent are incorporated by reference
- ☐ PCT National Phase Application
- ☐ Design Application
- ☐ Reissue Application
- ☐ Plant Application
- ☐ Substitute Specification
  - Sub. Spec Filed \_\_\_\_\_
  - in App. No. \_\_\_\_\_ / \_\_\_\_\_
- ☐ Marked up Specification re
  - Sub. Spec. filed \_\_\_\_\_
  - In App. No. \_\_\_\_\_ / \_\_\_\_\_

## SPECIFICATION

# TITLE OF THE INVENTION

APPARATUS AND METHOD FOR POSITIONING HEAD AT TARGET  
POSITION ON DISK

## CROSS-REFERENCE TO RELATED APPLICATIONS

5           This application is based upon and claims the  
benefit of priority from the prior Japanese Patent  
Application No. 2002-380276, filed December 27, 2002,  
the entire contents of which are incorporated herein  
by reference.

## 10                               BACKGROUND OF THE INVENTION

### 1. Field of the Invention

          The present invention relates to a disk drive  
that uses a head to read and write data from and to  
a disk, and in particular, to a disk drive that sets  
15       an offset between a track position specified by  
a command from a host and a target position at which  
the head is to be actually positioned, as well as  
a head positioning method used for this disk drive.

### 2. Description of the Related Art

20       A hard disk drive is well known as a disk drive  
that uses disks (disk media) as recording media.  
In general, a plurality of concentric servo tracks are  
arranged on a recording surface of a disk. The pitch  
of the servo tracks on the disk is fixed. Servo  
25       information is pre-written in each servo track  
discretely at equal intervals in the circumferential  
direction of the disk. The servo information

pre-written in the disk is called embedded servo. The servo information is a kind of positional information, also called a servo pattern, and contains address code and burst signals. The address code contains  
5 a cylinder code (cylinder number). The cylinder code indicates a cylinder position on the disk at which the corresponding servo information is written. The burst signal is also called a position error signal, and it indicates information (position error) on the position  
10 of the head relative to the cylinder (servo track) in which the corresponding servo information is written. The cylinder code in the servo information is a value that varies with the consecutive servo tracks (in general, the respective servo tracks have different  
15 values).

If a host utilizing the hard disk drive provides a read/write command to the drive, the position of a target track on the disk specified by this command is calculated. Then, head positioning control is carried  
20 out on the basis of the servo information read by the head. This control allows the head to be positioned at the target position (in the radial direction of the disk). In this state, the head reads or writes data from or to the disk. In this case, the tracks in  
25 which the head writes data coincide with the servo tracks. The pitch of the tracks (track pitch) is fixed.

The heads of recent hard disk drives are mainly of a composite type. The composite head is composed of a read head (read element) and a write head (write element) separately formed on the same slider. With a  
5 hard disk drive comprising such a composite head, the signal to noise ratio of a read signal (reproduction signal) is degraded if the head has a large azimuth angle. This is because crosstalk may occur, in which data recorded in a track on the disk is deleted by  
10 writing data in adjacent tracks.

Thus, techniques have hitherto been proposed which suppress the adverse effects of crosstalk. For example, Jpn. Pat. Appln. KOKAI Publication No. 10-255201 describes a technique of dividing the  
15 recording surface on the disk into areas with a large azimuth angle and areas with a small azimuth angle. The technique (hereinafter referred to as the prior art) described in this publication arranges servo tracks in each area, the tracks having a track pitch  
20 unique to that area. Specifically, in the prior art, servo information is written using different track pitches for the areas with the large azimuth angle and for the areas with the small azimuth angle.

Thus, in the prior art, in order to suppress the  
25 adverse effects of crosstalk resulting from the large azimuth angle of the head, it is necessary to write servo information using different track pitches for

the respective areas into which the recording surface has been divided on the basis of a difference in azimuth angle. However, the length (known as the head width) of the head in the radial direction of the disk varies with the head. Crosstalk may also occur if the width (write width) over which data is actually written varies owing to the variation in head width. In this case, different track pitches must be used to write servo information in the respective areas on the disk into which the recording surface is divided, also taking the variation in head width into account.

#### BRIEF SUMMARY OF THE INVENTION

According to an embodiment of the present invention, there is provided a disk drive comprising a disk having a recording surface on which a plurality of concentric tracks are arranged at a fixed pitch, wherein data is read from and written to the disk by a head arranged in association with the recording surface of the disk. The disk drive comprises calculating means, determining means, and executing means. The calculating means calculates a first offset value on the basis of the position of a first target track specified by a command from a host, the first offset value reflecting a track pitch which enables adverse effects of crosstalk to be suppressed. The first offset value indicates an offset of a target position at which the head is to be actually

positioned from a predetermined position on the first target track in a radial direction of the disk. The determining means determines a second target track, to which the target position belongs, and a second offset value on the basis of the position of the first target track and the first offset value calculated by the calculating means. The second offset value indicates an offset of the target position from a predetermined position on the second target track in the radial direction of the disk. The executing means executes control to position the head at the target position on the second target track on the basis of the second target track position and second offset value each determined by the determining means.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate embodiments of the invention, and together with the general description given above and the detailed description of the embodiments given below, serve to explain the principles of the invention.

FIG. 1 is a diagram showing the configuration of a hard disk drive according to an embodiment of the present invention;

FIG. 2A is a view showing the format of a recording surface  $H_i$  ( $i=0, 1$ ) of a disk 11;

FIG. 2B is a diagram showing that cylinder codes

with different values are written in consecutive servo tracks on the disk 11 at a fixed pitch;

FIGS. 3A and 3B are views showing the relationship between a set of areas  $A_1$  to  $A_n$  on recording surfaces  $H_0$  and  $H_1$  of the disk 11 and a set of offset values  $\Delta O_1$  to  $\Delta O_n$  for the respective areas  $A_1$  to  $A_n$ ;

FIG. 4 is a diagram showing an example of the structure of data in an offset table 222;

FIG. 5 is a diagram showing an example of the positional relationship between a first target track  $TT_1$  and a second target track  $TT_2$  if the first target track  $TT_1$  is each of the consecutive servo tracks  $T_{jk}$  on the disk 11;

FIG. 6 is a flow chart showing an operational procedure used when a command is executed;

FIG. 7 is a diagram showing an example of the relationship between both the first target track  $TT_1$  ( $=T_{jk}$ ) and offsets  $O_j$  and  $\Delta O_j$  and both the second target track  $TT_2$  and an offset  $\Delta O_j'$ ;

FIGS. 8A and 8B are diagrams showing that unique offset values are stored in FROMs 22 provided in respective HDDs having different data track pitches (track density);

FIGS. 9A and 9B are flow charts showing the procedure of a process for determining the offsets  $O_j$  and  $\Delta O_j$  for each area  $A_j$ ;

FIG. 10A is a diagram showing that a head  $12-i$

is positioned at a predetermined position on the track  $T_{jk}$ ;

FIG. 10B is a diagram showing that the head  $12_i$  is offset from the predetermined position on the track  $T_{jk}$  in a radially outside direction of the disk; and

FIG. 10C is a diagram showing that the head  $12_i$  is offset from the predetermined position on the track  $T_{jk}$  in a radially inward direction of the disk.

#### DETAILED DESCRIPTION OF THE INVENTION

With reference to the drawings, description will be given of an embodiment in which the present invention is applied to a hard disk drive. FIG. 1 is a block diagram showing the configuration of a hard disk drive (hereinafter referred to as an HDD) according to an embodiment of the present invention. In FIG. 1, a disk (magnetic disk medium) 11 has two disk surfaces including a top and bottom surfaces. At least one of the two disk surfaces of the disk 11, e.g. both disk surfaces constitute recording surfaces  $H_0$  and  $H_1$  on which data is magnetically recorded. Heads (magnetic heads)  $12_0$  and  $12_1$  are arranged in association with the recording surfaces  $H_0$  and  $H_1$ , respectively. The head  $12_i$  ( $i=0, 1$ ) is caused to float over the disk 11 by rotation of the disk 11 while the HDD is in operation. The head  $12_i$  is used to read data from the recording surface  $H_i$  of the disk 11 (data recording) and to write data to the recording



surface  $H_i$  of the disk 11 (data reproduction).

The head 12- $i$  is of a composite type in which a read head 121 and a write head 122 are separately formed on the same slider. The read head 121 is, for example, a  
5 magneto resistive head (MR head) composed of a magneto resistive (MR) element. The write head 122 is, for example, an inductive head composed of an inductive thin-film element. In the arrangement shown in FIG. 1, the HDD is assumed to comprise a single  
10 disk 11. However, the HDD may comprise a plurality of disks 11 stacked.

FIG. 2A shows the format of the recording surface  $H_i$  ( $i=0, 1$ ) of the disk 11. As shown in this figure, a plurality of servo areas 110 are arranged on the  
15 recording surface  $H_i$  of the disk 11 discretely at equal intervals in the circumferential direction of the disk 11 and radially in the radial direction of the disk 11. The area between the adjacent servo areas 110 on the recording surface  $H_i$  is used for user  
20 data. A plurality of data sectors are arranged in the user data area. A plurality of concentric servo tracks 111 are arranged on the recording surface  $H_i$  of the disk 11. The pitch (servo track pitch) of the servo tracks 111 is fixed. Servo information is  
25 pre-written in each servo area 110 for each servo track 111. Each servo information item contains cylinder code (cylinder number) and burst signals.

The cylinder code and the burst signals are positional information required to position the head 12<sub>-i</sub> at a target position on a target track. In this case, the cylinder code in the respective servo information items written in the servo area 110 for the respective servo tracks 111 are different values CYL (in general, different values).

Referring back to FIG. 1, the disk 11 is rotated at a high speed by a spindle motor (hereinafter referred to as an "SPM") 13. The head 12<sub>-i</sub> is attached to the tip of an actuator (carriage) 14. The head 12<sub>-i</sub> moves in the radial direction of the disk 11 as the actuator 14 moves rotatively. Thus, the head 12<sub>-i</sub> is positioned on a target track. The actuator 14 includes a voice coil motor (hereinafter referred to as a VCM) 15 serving as a driving source for the actuator 14. The SPM 13 and the VCM 15 are driven by driving currents independently supplied by a driver IC 16. The driver IC 16 is a motor driver composed of one chip. A CPU 21 determines the amount of control required to determine the driving currents supplied by the driver IC 16 to the SPM 13 and the VCM 15, respectively.

The head 12<sub>-i</sub> is connected to a head IC (head amplifier circuit) 17. The head IC 17 includes a read amplifier (not shown) that amplifies a read signal read by the head 12<sub>-i</sub> and a write amplifier (not

shown) that converts write data into a write current.

A head IC 23 is connected to a read/write IC

(read/write channel) 18. The read/write IC 18 is a signal processing device that executes various signal

5 processes. These signal processes include a process of subjecting a read signal to an analog-to-digital (A/D) conversion, a process of encoding write data, and a process of decoding digitalized read data.

The read/write IC 18 also has a function of pulsing

10 (binarizing) a read signal into a read pulse signal and a function of extracting burst signals (in this

case, burst signals A, B, C, and D) from servo information in accordance with a timing signal (burst timing signal) from a gate array 19. The burst

15 signals are transmitted to the CPU 21, which uses them for positioning control (track following control) to settle the head 12<sub>i</sub> at a target position on a target track.

The gate array 19 has a function of generating

20 various timing signals including a burst timing signal, from a read pulse signal outputted by the read/write IC 18 and a function of extracting cylinder code from servo information. The cylinder code is

used for seek control to move the head 12<sub>i</sub> to the

25 target track. A disk controller (hereinafter referred to as an "HDC") 20 is connected to a host (host system) utilizing the HDD. The host is digital

electronic equipment represented by a personal computer. The HDC 20 processes read data decoded by the read/write IC 21 in accordance with a control signal from the gate array 19 to generate data to be transmitted to the host. The HDC 20 also transfers write data transferred by the host, to the read/write IC 18 in accordance with a control signal from the gate array 19.

The CPU 21 is a main controller for the HDD.

The CPU 21 contains an FROM (Flash Read Only Memory) 22 and a RAM (Random Access Memory) 23. The FROM 22 is a rewritable nonvolatile memory. The FROM 22 pre-stores a control program 221 to be executed by the CPU 17. The control program 221 contains a process routine for determining a target position at which the head 12<sub>-i</sub> is to be actually positioned, on the basis of positional information on a target track specified by a command from the host. The target position is determined taking the azimuth angle of the head 12<sub>-i</sub> or the like into account. The FROM 22 also pre-stores an offset table 222, described later. A part of the entire area of the RAM 23 is used by the CPU 21 as a work area.

The offset table 222 indicates the relationship between concentric areas  $A_j$  ( $j=1$  to  $n$ ) (see FIGS. 3A and 3B) on the recording surfaces  $H_0$  and  $H_1$  of the disk 11 and both offset values  $O_j$  and  $\Delta O_j$ .

The recording surfaces  $H_0$  and  $H_1$  are divided into the areas  $A_j$  on the basis of the azimuth angle of each position of the head 12<sub>-i</sub> in the radial direction of the disk. A plurality of servo tracks 111 are arranged in each area  $A_j$ . Here, the offset value (fourth offset value)  $O_j$  will be described. First, it is assumed that a leading track  $T_{j0}$  in the area  $A_j$  is a target track  $TT_1$ . The target track  $TT_1$  (hereinafter referred to as a first target track  $TT_1$ ) is specified by a read/write command from the host. In the present embodiment, a target position (the position in the radial direction of the disk 11) TP at which the head 12<sub>-i</sub> is to be actually positioned does not always coincide with a predetermined position on the target track  $TT_1$ . If a track  $T_{j0}$  is assumed to be the track  $TT_1$ , the offset value  $O_j$  indicates the offset (for example, in the radially inward direction of the disk 11) of the target position TP from the predetermined position on the target track  $TT_1$  (= track  $T_{j0}$ ).

A track on the disk 11 to which a target position (TP) belongs is called a second target track  $TT_2$ . The predetermined position varies between a data read and a data write because the head 12<sub>-i</sub> is of the composite type. However, for simplification of description, the predetermined position is assumed to be on a center line in the target track  $TT_1$ .

The offset value (third offset value)  $\Delta O_j$

indicates the difference (pitch difference) between a servo track pitch STP and a data track pitch DTP. The data track pitch DTP enables the adverse effects of crosstalk to be suppressed. The DTP and the STP have the relationship expressed by the following equation:

$$DTP = STP + \Delta O_j \quad (1)$$

In the prior art, the data track pitch DTP is equal to the servo track pitch STP. That is,  $\Delta O_j = 0$ .

In this case, the target position TP coincides with the predetermined position on the target track  $TT_1$ . However, when the data track pitch DTP is equal to the servo track pitch STP, with some HDDs, the adverse effects of crosstalk become more significant. Such HDDs are classified into two types. A first type includes HDDs in which the head  $12_i$  has an azimuth angle varying markedly depending on the position on the disk in its radial direction. With the first type of HDD, owing to the varying azimuth angle of the head  $12_i$ , the width (write width) over which data is actually written by the head  $12_i$  also varies depending on the position on the disk in its radial direction. This is equivalent to the head width of the head  $12_i$  varying depending on the position on the disk in its radial direction. A second type includes HDDs in which the heads  $12_0$  and  $12_1$ , corresponding to the recording surfaces  $H_0$  and  $H_1$ , respectively, of

the disk 11, have greatly different head widths (which depend on the physical shapes of the heads). Thus, in the present embodiment, for each area  $A_j$ , a unique data track pitch DTP ( $DTP \geq STP$ ) is set which enables  
5 the adverse effects of crosstalk to be suppressed. Specifically, a unique offset value  $\Delta O_j$  is set for each area  $A_j$ .

The numbers of servo tracks 111 arranged in areas  $A_1$  to  $A_{j-1}$  are assumed to be  $N_1$  to  $N_{j-1}$ , respectively.  
10 The offset value  $O_j$  can be calculated in accordance with the following equation:

$$O_j = O_{j-1} + \Delta O_{j-1}(N_{j-1} - 1/2) + \Delta O_j/2 \quad (2)$$

Specifically, the offset value  $O_j$  can be calculated from  $O_{j-1}$ ,  $\Delta O_{j-1}$ , and  $\Delta O_j$ , as well as the  
15 number of tracks  $N_1$  to  $N_{j-1}$ . In this case,  $O_1 = \Delta O_1/2$ .

Alternatively, the offset value  $O_j$  can be calculated using the following equation:

$$\begin{aligned} O_j &= O_{j-1} + \Delta O_{j-1}(N_{j-1} - 1/2) + \Delta O_j/2 \\ &= \Delta O_1 * N_1 + \Delta O_2 * N_2 + \dots + \Delta O_{j-1} * N_{j-1} + \Delta O_j \\ 20 \quad &= \sum \Delta O_p * N_p + \Delta O_j \end{aligned} \quad (3)$$

Here,  $\sum \Delta O_p * N_p$  represents the sum of  $\Delta O_p * N_p$  for  $p=1$  to  $j-1$ . As is apparent from Equation (3), the offset value  $O_j$  can also be calculated from the offset values  $\Delta O_1$  to  $\Delta O_j$  and the number of tracks  
25  $N_1$  to  $N_{j-1}$ . Accordingly, if the time required to calculate the offset value  $O_j$  does not matter, information on the offset value  $O_j$  need not

necessarily be stored in an entry  $E_j$  in the offset table 222.

It is assumed that the  $k+1$ -th track  $T_{jk}$  in the area  $A_j$  is the first target track  $TT_1$ . In this case, the offset of the target position TP at which the head 12<sub>-1</sub> is to be actually positioned, from the predetermined position on the target track  $TT_1$  (=track  $T_{jk}$ ) is expressed by  $O_j + k(STP + \Delta O_j) = O_j + k \cdot DTP$ .

FIGS. 3A and 3B show the relationship between a set of the areas  $A_1$  to  $A_n$  on the recording surfaces  $H_0$  and  $H_1$  of the disk 11 and a set of the offset values  $\Delta O_1$  to  $\Delta O_n$  for the respective areas  $A_1$  to  $A_n$ . The offset values  $\Delta O_1$  to  $\Delta O_n$  are determined taking into account a difference in head width between the head 12<sub>-0</sub> and the head 12<sub>-1</sub> corresponding to the recording surfaces  $H_0$  and  $H_1$ , respectively.

FIG. 4 shows an example of the structure of data in the offset table 222. As shown in this figure, each entry  $E_j$  ( $j=1$  to  $n$ ) in the offset table 222 stores track position information indicative of a leading track  $T_{j0}$  of the servo tracks 111 contained in the area  $A_j$ , as well as the offset values  $O_j$  and  $\Delta O_j$ . Here, it is assumed that the first target track  $TT_1$  is the track  $T_{jk}$ ,  $T_{j0} \leq TT_1 < T_{(j+1)0}$ , and the track  $TT_1$  is contained in the area  $A_j$ . In this case, with reference to the entry  $E_j$  in the offset table 222, it is possible to obtain the offset values  $O_j$  and  $\Delta O_j$ .



required to determine the offset of the target position TP at which the head 12<sub>-i</sub> is to be actually positioned, from the (predetermined position on the) first target track TT<sub>1</sub>.

5           FIG. 5 shows an example of the positional relationship between the first target track TT<sub>1</sub> (=T<sub>jk</sub>) and a second target track TT<sub>2</sub> if the first target track TT<sub>1</sub> is each of the consecutive servo tracks T<sub>jk</sub> on the disk 11. In the example in FIG. 5, for the  
10           convenience of drawing, it is assumed that four tracks are contained in each of the areas A<sub>1</sub>, A<sub>2</sub>, and A<sub>3</sub>.

          The CPU 21 in FIG. 1 controls each section of the HDD in accordance with the control program 221 stored in the FROM 22. For example, CPU 21 executes seek  
15           control to move the head 12<sub>-i</sub> to the second target track TT<sub>2</sub> on the disk 11. The second target track TT<sub>2</sub> is determined on the basis of the first target track TT<sub>1</sub> and the offset values O<sub>j</sub> and ΔO<sub>j</sub>. Specifically, the second target track TT<sub>2</sub> is obtained by correcting  
20           the first target track TT<sub>1</sub> on the basis of the offset values O<sub>j</sub> and ΔO<sub>j</sub>; the head 12<sub>-i</sub> is to be actually moved to the second target track TT<sub>2</sub>. The CPU 21 also executes positioning control to the position the head  
25           12<sub>-i</sub> moved to the second target track TT<sub>2</sub>, at the target position TP on the target track TT<sub>2</sub>. The value ΔO<sub>j</sub>' for the offset of the target position TP from the predetermined position on the second target track

TT<sub>2</sub> is determined on the basis of the first target track TT<sub>1</sub> and the offset values O<sub>j</sub> and ΔO<sub>j</sub>. The CPU 21 also uses the HDC 20 to execute read/write control in accordance with a read/write command from the host.

5           Now, with reference to the flow chart in FIG. 6, description will be given of execution of a read/write command in the HDD shown in FIG. 1, taking by way of example the case in which a write command from the host is executed. It is assumed that the host  
10           provides a write command to the HDD shown in FIG. 1. The write command is received by the HDC 20, which then passes the command to the CPU 21. If a read command or a write command has been delivered by the HDC 20, the CPU 21 calculates the position of the  
15           first target track TT<sub>1</sub> specified by this command. (step S1). Normally, a read/write command from the host specifies a disk address using a logic address (logic block address). Thus, to access the disk 11, it is necessary in step S1 to execute a calculation process  
20           to convert the logic address into a physical address representative of the first target track TT<sub>1</sub>. Here, it is assumed that the first target track TT<sub>1</sub> is the track T<sub>jk</sub>.

          Once the CPU 21 identifies the position of the  
25           first target track TT<sub>1</sub> (step S2), it identifies the area A<sub>j</sub> on the disk 11 to which the target track TT<sub>1</sub> (=T<sub>jk</sub>) belongs (step S2). The area A<sub>j</sub> is one of the

areas  $A_1$  to  $A_n$  (see FIGS. 3A and 3B) into which the recording surface  $H_0$  and  $H_1$  are divided. Then, the CPU 21 references the entry  $E_j$  in the offset table 222 which corresponds to the area  $A_j$  identified in step S2 (step S3). Then, the CPU 21 reads the offset values  $O_j$  and  $\Delta O_j$  stored in the referenced entry  $E_j$  (step S4). On the basis of the first target track  $TT_1$  ( $=T_{jk}$ ) and the offset values  $O_j$  and  $\Delta O_j$  read in step S4, the CPU 21 calculates the value of the offset (first offset value)  $\{O_j + k(STP + \Delta O_j)\}$  of the target position on the second target track  $TT_2$  from a predetermined position on the first target track  $TT_1$  (Step S5). This offset value  $\{O_j + k(STP + \Delta O_j)\}$  reflects a data track pitch that enables the adverse effects of crosstalk to be suppressed.

Then, on the basis of the target track  $TT_1$  ( $=T_{jk}$ ) and the offset value  $\{O_j + k(STP + \Delta O_j)\}$ , CPU 21 determines the position of the second target track  $TT_2$  and the offset value (second offset value)  $\Delta O_j'$  (step S6). As described previously, the offset value  $O_j$  can also be calculated in accordance with Equation (3) on the basis of the offset value  $\Delta O_1$  to  $\Delta O_j$ . Therefore, the position of the second target track  $TT_2$  and the offset value  $\Delta O_j'$  can be determined from the first target track  $TT_1$  ( $T_{jk}$ ) and the offset values  $\Delta O_1$  to  $\Delta O_j$ .

As described previously, the head 12-i is to

be actually moved to the second target track  $TT_2$ . Specifically, the target position TP (at which the head  $12_j$  is positioned) that is offset from the predetermined position on the leading track  $T_{j0}$  in the area  $A_j$  by the offset value  $\{O_j + k(STP + \Delta O_j)\}$  belongs to the second target track  $TT_2$  (servo track 111). On the other hand, the offset value  $\Delta O_j'$  indicates the offset of the target position TP on the second target track  $TT_2$  from predetermined position on the target track  $TT_2$ . FIG. 7 shows an example of the relationship between both the first track  $TT_1 (=T_{jk})$  and offsets  $O_j$  and  $\Delta O_j$  and both the second target track  $TT_2$  and an offset  $\Delta O_j'$ .

Then, the CPU 21 executes seek control to move the head  $12_i$  to the target track  $TT_2$  determined in step S6 (step S7). This seek control is executed on the basis of a cylinder code extracted from the gate array 19. When the head  $12_j$  is moved to the second target track  $TT_2$ , the CPU 21 executes positioning control (tracking control) to position (settle) the head  $12_i$  at the target position TP on the target track  $TT_2$  (step S8). This positioning control is based on burst signals extracted by the read/write IC 18. The target position TP at which the head  $12_i$  is to be positioned in this positioning control is offset from the predetermined position on the second target track  $TT_2$  in the radial direction of the disk 11 by

the offset value  $\Delta O_j'$ . When the head 12<sub>-i</sub> is positioned within a predetermined error range from the target position TP (in this case, the target position for a write) on the second target track TT<sub>2</sub>, the CPU  
5 21 proceeds to step S9. In step S9, the CPU 21 causes the head 12<sub>-i</sub> to execute a read/write (in this case, a write).

Thus, in the present embodiment, the target position TP at which the head 12<sub>-i</sub> is to be positioned  
10 is determined to be a position on the target track TT<sub>2</sub> instead of the predetermined position on the first target track TT<sub>1</sub> specified by a command from the host. The position on the second target track TT<sub>2</sub> is offset from the predetermined position on the first target  
15 track TT<sub>1</sub> in the radial direction of the disk 11 by the offset value (first offset value)  $\{O_j + k(STP + \Delta O_j)\}$ . This offset value reflects a track pitch that enables the adverse effects of crosstalk to be suppressed. Accordingly, by positioning the head 12<sub>-i</sub> at the  
20 determined target position TP and executing a read/write, it is possible to achieve a data track pitch DTP that enables the use of the disk 11 in which the servo tracks 111 are arranged at a fixed pitch (servo track pitch) STP, with the adverse effects of  
25 crosstalk suppressed.

In the above embodiment, the areas A<sub>1</sub> to A<sub>n</sub> on the recording surfaces H<sub>0</sub> and H<sub>1</sub> of the disk 11 and

the offset values  $O_1$  to  $O_n$  and  $\Delta O_1$  to  $\Delta O_n$  for the respective areas  $A_1$  to  $A_n$  are determined taking into account a difference in the azimuth angle of the heads 12-0 and 12-1 at each position on the disk in the radial direction, as well as a difference in head width between the heads 12-0 and 12-1. However, only one of these two differences may be taken into account. For example, if only the difference in azimuth angle is taken into account, each of the recording surfaces  $H_0$  and  $H_1$  of the disk 11 may be similarly divided into a plurality of concentric areas. In this case, the adverse effects of the difference in head width between the heads 12-0 and 12-1 may remain. These adverse effects are eliminated by determining the offset values  $O_1$  to  $O_n$  and  $\Delta O_1$  to  $\Delta O_n$  on the basis of the upper limit value in the appropriate standard for the head widths of the heads 12-0 and 12-1.

If only the difference in head width between the heads 12-0 and 12-1 is taken into account, the entire recording surfaces  $H_0$  and  $H_1$  of the disk 11 may correspond to the areas  $A_0$  and  $A_1$ , respectively. Here, the offset values  $O_i$  and  $\Delta O_i$  (or  $\Delta O_i$ ) may be set for each recording surface  $H_i$  ( $i=0, 1$ ). The offset values  $O_i$  and  $\Delta O_i$  can be determined (calculated) from the head width of the head 12-i by measuring the head width during the manufacture of the

HDD (or the head 12-<sub>i</sub>). The offset values  $O_i$  and  $\Delta O_i$  (or  $\Delta O_i$ ) determined may be stored in the FROM 22, for example, in a format similar to that for the offset table 222, shown in FIG. 4. Here, information  
5 indicative of the recording surface  $H_i$  (head 12-<sub>i</sub>) can be used in place of information (track position information indicative of the leading track) on the area  $A_i$  paired with the offset values  $O_i$  and  $\Delta O_i$  (or  $\Delta O_i$ ). In this example, the number of entries in the  
10 offset table 222 can be sharply reduced. However, the adverse effects of the difference in the azimuth angle at each position on the disk in its radial direction between the heads 12-<sub>i</sub> may remain. These adverse effects are eliminated by determining the offset  
15 values  $O_1$  to  $O_n$  and  $\Delta O_1$  to  $\Delta O_n$  on the basis of the upper limit value in the appropriate standard for the head widths of the heads 12-<sub>0</sub> and 12-<sub>1</sub>.

Furthermore, if only the difference in head width is taken into account, the heads are classified into,  
20 for example, first heads having a head width meeting a first standard and second heads having a head width which is outside the first standard but which meets a second standard. This classification serves to provide HDDs such as those described below. First,  
25 the upper limit value of the head width in the first standard is defined as  $HW_{UL1}$ . The upper limit value of the head width in the second standard is defined as

HW<sub>UL2</sub> (HW<sub>UL2</sub>>HW<sub>UL1</sub>). Then, the heads are classified into the first heads having a head width meeting the first standard, the second heads having a head width which is outside the first standard but which meets  
5 the second standard, and third heads having a head width that is also outside the second standard. The third heads are treated as defectives that cannot be mounted in HDDs. On the other hand, the first heads are mounted in a first HDD that realizes a first data  
10 track pitch DTP (first track density). The second heads are mounted in a second HDD that realizes a second data track pitch DTP (second track density) larger than the first data track pitch DTP (first track density). The offset value  $O_1$  ( $=\Delta O_1/2$ )  
15 determined from the head width HW<sub>UL1</sub> is stored in a predetermined position in the FROM 22 in the first HDD, as shown in FIG. 8A. The offset value  $O_1$  is stored in the FROM 22 in the first HDD while this HDD is being manufactured. On the other hand, the offset  
20 value  $O_2$  ( $=\Delta O_2/2$ ) determined from the head width HW<sub>UL2</sub> is stored in a predetermined position in the FROM 22 in the second HDD, as shown in FIG. 8B. The offset value  $O_2$  is stored in the FROM 22 in the second HDD while this HDD is being manufactured.  
25 The relationship between the offset values  $O_1$  and  $O_2$  is  $O_1 < O_2$ . Consequently, the use of the second head enables the second HDD to be manufactured in spite of



a decrease in track density compared to the first HDD manufactured using the first head. That is, it is possible to effectively utilize the second head, having a head width which is outside the first  
5 standard but which meets the second standard.

Now, a process of determining the offset values  $O_j$  and  $\Delta O_j$  for each area  $A_j$  will be described with reference to the flow charts in FIGS. 9A and 9B and FIGS. 10A, 10B, and 10C showing the head position.  
10 Here, for simplification of description, it is assumed that the entire recording surfaces  $H_0$  and  $H_1$  of the disk 11 are divided into a number  $n$  of areas  $A_j$ , i.e.  $A_1$  to  $A_n$  for management. First, the CPU 21 sets a pointer  $j$  specifying the area  $A_j$ , at an initial value  
15 of 1 and sets a variable  $h$  for determining the offset value, at an initial value of 1 (step S11). Then, the CPU 21 selects the track (servo track)  $T_{jk}$  from the area  $A_j$  on the disk 11 (step S12). Here, it is assumed that the track  $T_{jk}$  is one of the servo tracks  
20 111 in the area  $A_j$  which lies at an intermediate position in the radial direction of the disk. However, the track  $T_{jk}$  may be located at another position in the area  $A_j$ .

Then, the CPU 21 executes control to position the  
25 head 12- $i$  corresponding to the recording surface  $H_i$  on which the area  $A_j$  exists, at a predetermined position on the track  $T_{jk}$  (step S13). In step S13, the CPU 21

executes seek control to move the head 12<sub>-i</sub> to the track T<sub>jk</sub>. The CPU 21 also executes positioning control to position the head 12<sub>-i</sub> moved to the track T<sub>jk</sub>, at a predetermined position on the track T<sub>jk</sub>.

5 FIG. 10A shows that the head 12<sub>-i</sub> is positioned at the predetermined position on the track T<sub>jk</sub>. In the state shown in FIG. 10A, the CPU 21 causes the head 12<sub>-i</sub> to write one track (for example, 512 sectors) of first test data to the disk 11 (step S14). Then, the CPU 21  
10 causes the head 12<sub>-i</sub> to read data from the track T<sub>jk</sub> and measures an error rate ER<sub>1</sub> indicative of the rate of a read error (step S15). The measured error rate ER<sub>1</sub> is stored in a first area in the RAM 23.

Then, the CPU 21 executes control to shift  
15 the position of the head 12<sub>-i</sub> from the track T<sub>jk</sub> (the predetermined position on the track T<sub>jk</sub>) in a radially outward direction of the disk 11 by the amount  $STP + (h-1) \cdot \Delta O$  (step S16). FIG. 11B shows that the position of the head 12<sub>-i</sub> has been shifted from  
20 the track T<sub>jk</sub> in the radially outward direction of the disk 11 by the amount  $STP + (h-1) \cdot \Delta O$ . For h=1, the value of the offset of the head 12<sub>-i</sub> from the track T<sub>jk</sub> equals the STP (Servo Track Pitch). In the state shown in FIG. 11B, the CPU 21 causes the head 12<sub>-i</sub> to  
25 write one track of second test data to the disk 11 (step S17). Then, the CPU 21 executes control to shift the position of the head 12<sub>-i</sub> from the track T<sub>jk</sub>

(the predetermined position on the track  $T_{jk}$ ) in a radially inward direction of the disk 11 by the amount  $STP+(h-1)*\Delta O$  (step S18). FIG. 11C shows that the position of the head 12<sub>i</sub> has been shifted from the track  $T_{jk}$  in the radially inward direction of the disk 11 by the amount  $STP+(h-1)*\Delta O$ . This position of the head 12<sub>i</sub> is offset from the position shown in FIG. 11B by the amount  $2\{STP+(h-1)*\Delta O\}$ .

In the state shown in FIG. 11C, the CPU 21 causes the head 12<sub>i</sub> to write one track of second test data to the disk (step S19). Then, the CPU 21 executes control to return the head 12<sub>i</sub> to the position of the track  $T_{jk}$  (step S20). The CPU 21 causes the head 12<sub>i</sub> to read data from the track  $T_{jk}$  and measures an error rate  $ER_2$  indicative of the rate of a read error (step S21). The measured error rate  $ER_2$  is stored in a second area in the RAM 23. Then, on the basis of the error rates  $ER_1$  and  $ER_2$  stored in the first and second areas, respectively, in the RAM 23, the CPU 21 makes determinations described below. The CPU determines whether or not the value  $ER_2-ER_1$  is smaller than a threshold TH (step S22).

Here, it is assumed that  $ER_2-ER_1 \geq TH$ . In this case, the CPU 21 determines that the writes of the second test data in steps S17 and S19 adversely affects the first test data written in the track  $T_{jk}$ . That is, the CPU 21 determines that the adverse

effects of crosstalk cannot be eliminated even by writing data while shifting the head 12<sub>-i</sub> from the track T<sub>jk</sub> in the radially outward or inward direction of the disk 11 by the amount STP+(h-1)\*ΔO. Then, the  
5 CPU 21 executes step S23, described later, in order to suppress the adverse effects of crosstalk.

Specifically, the CPU 21 increments a variable h by 1 in order to increase the value of the offset of the head 12<sub>-i</sub> from the track T<sub>jk</sub> (step S23). Then, the  
10 CPU 21 uses the incremented variable h to execute steps S14 to S22, described later. That is, the CPU 21 repeats steps S14 to S22 while incrementing the variable h by 1 until ER<sub>2</sub>-ER<sub>1</sub><TH (step S23).

It is assumed that ER<sub>2</sub>-ER<sub>1</sub><TH. In this case, the  
15 CPU 21 determines that the current value of the offset of the head 12<sub>-i</sub> from the track T<sub>jk</sub> is the minimum offset value required to eliminate the adverse effects of crosstalk. Then, the CPU 21 determines whether or not the pointer j is 1 (initial value) (step S24).

20 If the pointer j is 1, the CPU 21 determines the offset values ΔO<sub>j</sub> and O<sub>j</sub> unique to the area A<sub>j</sub> in accordance with the following equation (step S25):

$$\begin{aligned}\Delta O_j &= 2(h-1) * \Delta O \\ O_j &= \Delta O_j / 2\end{aligned}\tag{4}$$

25 On the other hand, if the pointer j is not 1, the CPU 21 determines the offset values ΔO<sub>j</sub> and O<sub>j</sub> unique to the area A<sub>j</sub> in accordance with the following

equation (step S26):

$$\Delta O_j = 2(h-1) * \Delta O$$

$$O_j = O_{j-1} + \Delta O_{j-1} (N_{j-1} - 1/2) + \Delta O_j / 2 \quad (5)$$

Then, the CPU 21 stores information indicative of  
5 the leading track  $T_{j0}$  in the area  $A_j$  and information  
indicative of the offset values  $O_j$  and  $\Delta O_j$   
determined, in the entry  $E_j$  in the offset table 222,  
retained in the FROM 22 (step S27). Then, the CPU 21  
determines whether or not the pointer  $j$  is  $n$ ,  
10 indicating the final area  $A_n$  (step S24). If the  
pointer  $j$  is not  $n$ , the CPU 21 increments the pointer  
 $j$  by one and sets the variable  $h$  at 1 (initial value)  
(step S29). Then, the CPU 21 executes the process  
starting with step S12 in order to determine the  
15 values  $\Delta O_j$  and  $O_j$  unique to the area  $A_j$  indicated  
by the incremented pointer  $j$ . That is, the CPU 21  
repeats the process starting with step S12 until the  
pointer  $j$  becomes  $n$  and the values  $\Delta O_j$  and  $O_j$  unique  
to the area  $A_n$  are determined. Then, if it is  
20 determined at step S28 that the pointer  $j$  is  $n$ , the  
CPU 21 ends the process of determining the offsets  $O_j$   
and  $\Delta O_j$ .

In the above described process of determining the  
 $O_j$  and  $\Delta O_j$ , for simplification of description, the  
25 process from steps S13 to S21 is executed only once  
for a certain  $h$ . However, for measurement accuracy,  
the process from steps S13 to S21 may be repeated

a predetermined number of times  $\underline{r}$ . In this case,  
it may be determined whether or not the value  
 $((\sum (ER_2) - \sum (ER_1))/r)$  is smaller than the threshold TH.  
The value  $((\sum (ER_2) - \sum (ER_1))/r)$  is obtained by  
5 subtracting the average of error rates  $ER_1$  ( $\sum (ER_1)/r$ )  
from the average of error rates  $ER_2$  ( $\sum (ER_2)/r$ ).

In the above embodiment, the heads 12<sub>-0</sub> and 12<sub>-1</sub>  
are each of a composite type. However, the heads 12<sub>-0</sub>  
and 12<sub>-1</sub> may each be of an inductive type that uses  
10 a common element to execute read/write. In this case,  
the head width of the heads 12<sub>-0</sub> and 12<sub>-1</sub> has only to  
be taken into account. The recording surfaces  $H_0$  and  
 $H_1$  of the disk 11 may be managed as areas  $A_0$  and  $A_1$ ,  
respectively.

15 In the description of the above embodiment, the  
present invention is applied to the HDD (Hard Disk  
Drive). However, the present invention is applicable  
to disk drives other than HDDs, such as magneto-  
optical disk drives provided that their heads read and  
20 write data from and to a disk.

Additional advantages and modifications will  
readily occur to those skilled in the art. Therefore,  
the invention in its broader aspects is not limited to  
the specific details and representative embodiments  
25 shown and described herein. Accordingly, various  
modifications may be made without departing from the  
spirit or scope of the general inventive concept as

defined by the appended claims and their equivalents.